Detecting climate change

by Francis ZWIERS[1], Howard CATTLE[2], Thomas C. PETERSON[3] and Abdalah MOKSSIT[4]

Introduction

Detection of change in climate against its variability is a key issue in climate research. As an activity, climate change detection needs to address both global and regional responses to the external drivers of climate change, particularly those that result from human activity. It clearly needs and must build on long-term monitoring of key climate variables of the atmosphere, ocean and the land surface and ice cover (cryosphere) across the globe. It also needs to take advantage of a wide range of historical data and to engage in data rescue, quality control and homogenization of datasets. For assessment purposes, indices that characterize, and act as indicators of, change are essential tools.

The Open Programme Area Group (OPAG) of WMO's Commission for Climatology (CCl) (see www.wmo.ch) on the Monitoring and Analysis of Climate Variability and Change provides the focus for activities including dataset assembly and cataloguing, climate system monitoring, and climate variability and change detection. Its Expert Teams enhance the ways that raw material (climate data) are turned into products in their own right (climate datasets and assessments), which are in turn the building blocks to be assembled into other outputs of climate services (climate alert systems, predictions, and applications that support the protection of life and the promotion of sustainable development). Some activities underway include the development of guidelines for operational services involving metadata and homogenization, the collection and assembly of the ninth in the series of World Weather Records, and the synthesis and preparation of WMO's annual and multi-year reports on the status of the global climate. Information on some of those activities appears in other articles in this issue.

In recognition of the mutual benefit of linking research with operational service in appropriate ways, the CCl teamed up with the Climate Variability and Predictability Project ((CLIVAR) see www.clivar.org) of the World Climate Research Programme (WCRP) to create a joint Expert Team on Climate Change Detection, Monitoring and Indices (ET/CCDMI). This article describes the planned activities of this joint Expert Team and the accomplishments of its predecessor the joint CCl/CLIVAR Working Group on Climate Change Detection. Chaired by T. Peterson (USA), the main aim of this Working Group was to enhance the availability of information that is required to detect climate change in data-sparse regions. It has done this by promoting regional climate change workshops involving hands-on data analysis of climate indices for use in detection studies. The workshops build capacity in developing countries' National Meteorological and Hydrological Services that is immediately useful in the study of their climates and in their provision of climate-monitoring services.

The ET/CCDMI consists of four CCl representatives: A. Mokssit (Morocco), C. Folland (United Kingdom), S. Sensoy (Turkey) and L. Molion (Brazil) and four CLIVAR representatives: F. Zwiers (Canada), N. Bindoff (Australia), P. Jones (United Kingdom) and D. Karoly (USA). A. Mokssit and F. Zwiers serve as Co-Leads of the Expert Team. The team plans to focus its effort in five areas:

- Further develop and publicize indices and indicators of climate change and variability, with particular emphasis on the creation of indices of daily-to-seasonal extremes covering the global land surface using standardized software packages;
- Further develop other indices of value to the Intergovernmental Panel on Climate Change (IPCC), related to changes in mean climate and its variability from the subsurface of the oceans to the stratosphere;

1 Meteorological Service of Canada, Victoria, BC, Canada; and Co-Lead of the CCl Expert Team on Climate Change Detection, Monitoring and Indices (jointly with CLIVAR)

2 International CLIVAR Project Office, Southampton, United Kingdom

3 National Climatic Data Center/NESDIS/NOAA, Asheville, NC, U.S.; and Chair of the CCl OPAG on Monitoring and Analysis of Climate Variability and Change

4 Direction de la Météorologie Nationale, Casablanca, Morocco; and Co-Lead of the CCl Expert Team on Climate Change Detection, Monitoring and Indices (jointly with CLIVAR)

- Provide input on indices to WMO publications such as the Annual Statement on the Status of the Global Climate;
- Compare modelled and observed indices, and report on the comparisons, with some emphasis on changing extremes;
- Collaborate with and provide inputs to other groups, especially those set up under IPCC auspices, regarding the adequacy of the Global Observing System and the development of indices.

Past activities

The ET/CCDMI is continuing the efforts of its predecessor to enhance the availability of information that is required to detect climate change in data-sparse regions through dedicated climate change workshops. Under the auspices of the earlier Working Group, two workshops were held: in the Caribbean (University of West Indies, Mona, Jamaica, 8-12 January 2001, Taylor, 2001; Peterson *et al.*, 2002) and in Africa (Direction de la Météorologie Nationale, Casablanca, Morocco, 18-23 February 2001, Mokssit, 2003; Easterling *et al.*, 2003). A brief outline of the outcome of both workshops is presented here. The reader is referred to the references above for more detail.

The Caribbean Workshop

This workshop brought together scientists and data from around the Caribbean and made analyses of extremes derived from daily weather observations in the region. Held in Kingston, Jamaica, the workshop attracted participants from 18 of the 21 Meteorological Services. The participants brought data with them and time was split between lectures, seminars and discussions, and hands-on analysis at the University of West Indies computer centre. In addition to providing a preliminary analysis of data, the workshop fostered considerable interest and enthusiasm for data analysis and data archaeology.

Data from 30 stations were utilized, primarily on Caribbean Islands. However, one coastal Florida station was used and four stations in Belize. The data were subjected to a wide and fairly comprehensive variety of quality-control tests similar to those described in Peterson *et al*. (1998). Following the quality control and checks for homogeneity, various Caribbean-relevant indices were calculated as described on the Royal Netherlands Meteorological Institute (KNMI) indices Website (http://www. knmi.nl/samenw/eca/htmls/index2.html)

Several insights were gained through this analysis. One is that the climate of the Caribbean has changed. The extreme annual temperature range has decreased and the number of very warm days and nights has increased dramatically (Figure 1) while the number of very cool days and nights has decreased (Figure 2). The maximum number of consecutive very dry days has also decreased (Figure 3) and the number of heavy rainfall events has increased. These changes are similar to those found in a global analysis by Frich *et al.* (2002). Indices of some of these variables show relationships with hurricanes and sea-surface temperatures, but no one factor dominates all the observed changes.

In the process of creating the analysis, insights into the value of digital records of weather were gained and, as a result, increased efforts to digitize available paper archives were started in several Caribbean countries, some of which were used in a subsequent post-workshop analysis (Peterson *et al.*, 2002). Thanks to agreements from all the participat-

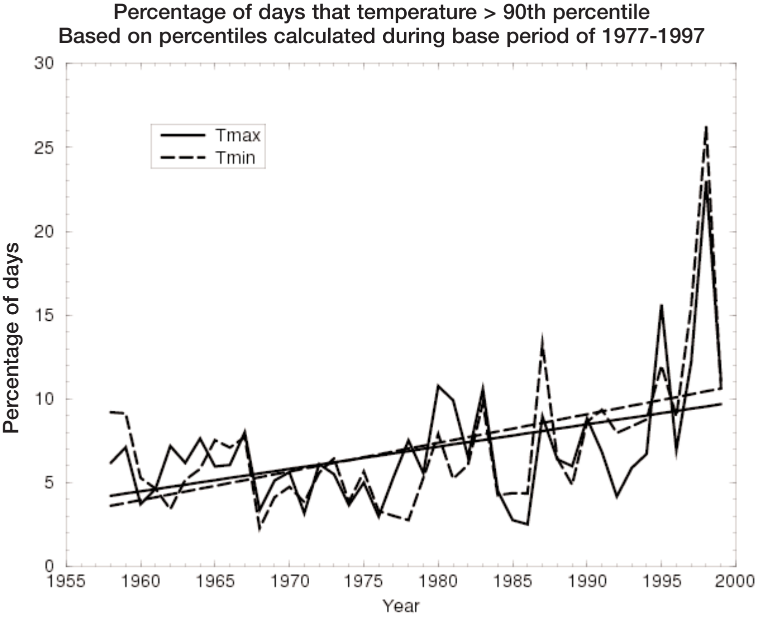

Figure 1 — Results from the Caribbean workshop: changes in the number of warm days and warm nights (from Peterson et al., 2002)

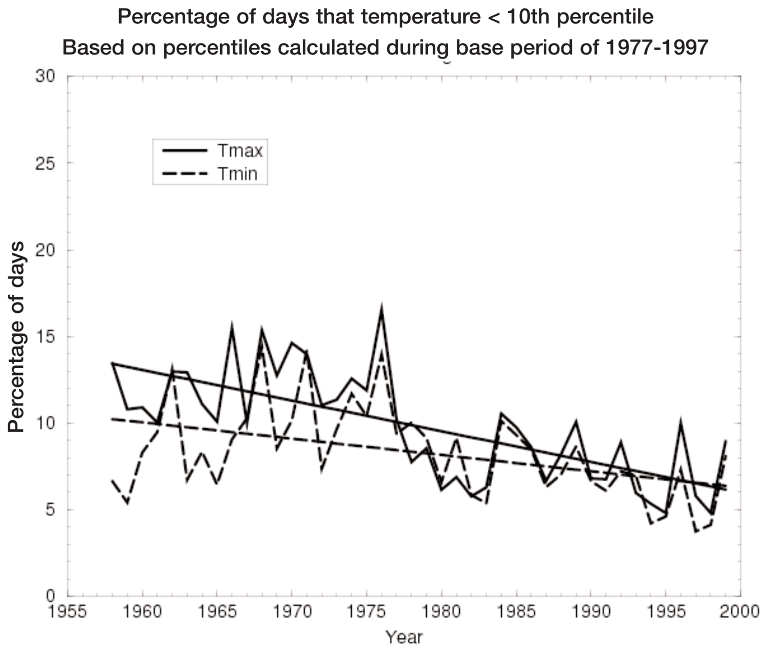

Figure 2 — Results from the Caribbean workshop: changes in number of cold days and cold nights (from Peterson et al., 2002)

ing meteorological services, all the data used in this regional analysis are being made available to researchers worldwide through the University of the West Indies.

The Casablanca Workshop

This workshop followed much the same format as the Caribbean one and indeed was held only a few weeks later. It too aimed at capacity building and attracted 28 participants from 23 African countries and Spain. It was conducted by a research team from the Met Office, Hadley Centre, United Kingdom, the National Climatic Data Center/NOAA, USA, the National Meteorological Research Centre/DMN, Morocco, and WMO. The workshop used daily data from 23 national archives in Africa to create relevant climate indices from the KNMI Website.

Overall, the results demonstrated positive trends in extreme warm night-time temperatures over most countries, including Madagascar and the Seychelles, except on the extreme eastern coast of the Republic of Tanzania (Figure 4). Similar results were found for daily maximum temperatures but for these the Tanzanian east coast showed similar results to all other countries (Figure 5). There is evidence of warming in almost all countries, with the warming found to be statistically significant in most cases.

Unlike temperature, precipitation indices showed very different trends from location to location making it difficult to assess the results of the analysis regionally. Extreme rainfall events appear to have increased in some locations and decreased in others, sometimes very close to those showing an increase. 3

These workshops, and others that preceded them such as those organized by the Asian Pacific Network of the Australian Bureau of Meteorology, are a very effective way in which to engage local scientists in the quality control, homogenization and analysis of the data collected in their countries. They build research and analysis capacity, and provide means by which reliable results on

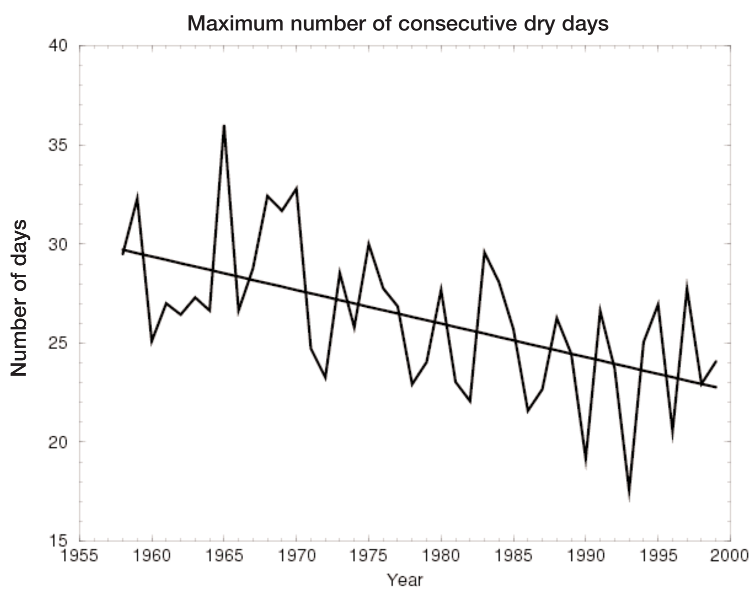

Figure 3 — Results from the Caribbean workshop: changes in maximum number of consecutive dry days (from Peterson et al., 2002)

regional climate change can contribute to the accumulating body of knowledge on secular change in our climate. Plans for additional workshops under the auspices of the ET/CCDMI in South America and southern Africa are described below.

Recent activities

Following its reconstitution, the work of the Expert Team has begun with a review of developments relevant to its activities. One such development is the considerable amount of work using climate indices that has recently appeared in the literature, and is underway. This includes the European Climate Assessment Report (Klein-Tank *et al.*, 2002), which provides a comprehensive assessment that is based on changes in indices describing both the mean climate and climate extremes. Also, there has been an increasing number of papers appearing in the literature that base their conclusions on indices of the mean and extreme climate (e.g. Folland and Anderson, 2002; Frich *et al.*, 2002; Braganza *et al.*, 2003; Karoly, 2003; Kiktev *et al.*, 2003). In addition, there is a substantial amount of work utilizing and developing climate indices that is being coordinated through European Commission (EC) funded projects. These include the MICE Project (Modelling the Impacts of Climate Extremes—http://www.cru.uea.ac.uk/projects/mice/index.html), the STARDEX Project (statistical and regional dynamical downscaling of extremes for Europe—http://www.cru.uea.ac.uk/projects/stardex/), and the EMULATE Project (European and North Atlantic daily to multidecadal climate variability—http://www.cru.uea.ac.uk/cru/projects/emulate/).

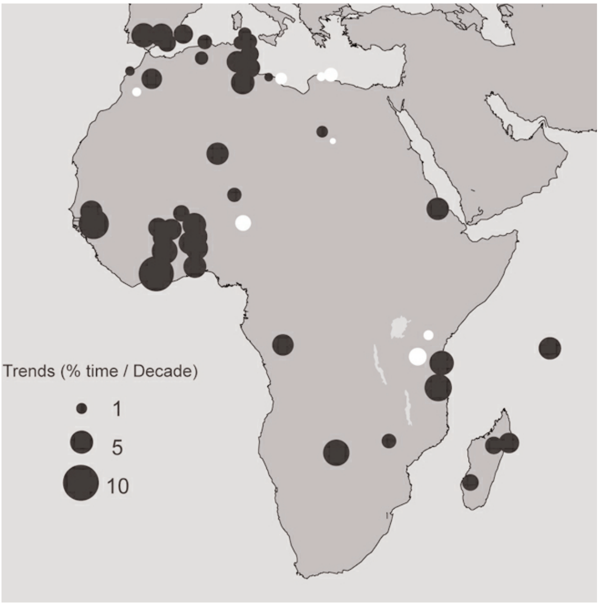

Figure 4 — Results from the Casablanca workshop: changes in the number of warm nights. Dark circles represent warming and white circles cooling. (From Easterling *et al.*, 2003)

Directly relevant to the work of the Team is renewal by NOAA and the US Department of Energy of the "Ad Hoc" detection group that was formerly lead by Dr T. Barnett. The newly reconstituted group, now lead by Dr T. Crowley and Dr G. Hegerl (both of Duke University, Raleigh, North Carolina) promotes the exchange of data between the major climate modelling centres and is working actively on the detection of anthropogenic change on regional scales and in climatic extremes.

Several approaches to regional detection are under consideration by the Expert Team. Some early results include those from Zwiers and Zhang (2003), who use a standard optimal detection formalism and are able to detect an anthropogenic signal in North American and Eurasian surface air temperature data. Karoly (2003), who uses a combination of climate change indices for North America, also concludes that there is strong evidence of an anthropogenic influence. Using a general linear model approach and an appropriate experimental design, Sexton *et al.* (2003) show the ability of an atmospheric general circulation model forced with observed sea-surface temperature and a variety of anthropogenic forcings to detect many regional anthropogenic signals down to the model grid scale.

Evidence of anthropogenic change is also being detected in other parts of the climate system. For example, changes are being observed in the global oceans that are consistent with anthropogenic forcing of the climate system (e.g. Barnett *et al.*, 2001; Reichert *et al.*, 2002; Banks and Bindoff, 2003; Pielke, 2003). Also, an anthropogenic signal has been detected in sea-level pressure data (Gillett *et al.*, 2003) and in changes in tropopause height (Santer *et al.*, 2003 a, b). While anthropogenic change has not yet been detected in precipitation data, evidence is emerging that the effect of natural external forcing (variations in solar output and volcanic activity) may be detectable (Allan and Ingram, 2002). In addition, there is a growing interest in the question of whether there has been an anthropogenic influence on observed changes in precipitation and temperature extremes, and thus there has been some preliminary work on the detection of such changes (e.g. Hegerl *et al.*, 2003).

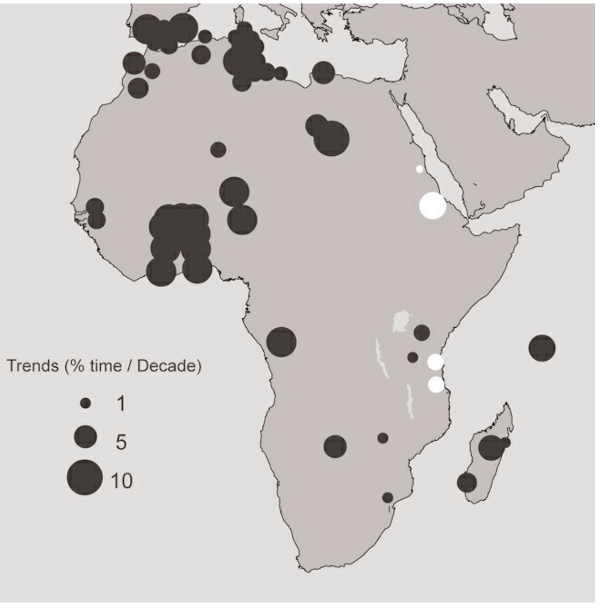

Figure 5 — Results from the Casablanca workshop: changes in the number of warm days. Dark circles represent warming and white circles cooling. From Easterling et al., 2003.

Future activities

A main thrust of the ET/CCDMI during the coming year will be to develop additional workshops on climate-change indices for data-sparse regions. The ET/CCDMI is developing plans for two additional regional climate change workshops that are designed to enhance the capacity of scientists in developing countries to quality-control their climate data and to contribute indices computed from those data to global and regional detection studies. It also recognizes the need to further develop and to publicize indices and indicators of climate change and variability, and to make available the associated standardized software packages.

The main priority is to organize a regional climate change workshop in South America that will help fill the large data void that presently exists in that part of the world. Contact is being made with a number of regional scientists to explore possible venues, establish potential participants, and seek funding.

As a second priority, the team also plans to exploit an opportunity in southern Africa to collocate a workshop with the 9th International Meeting on Statistical Climatology that will be held in Cape Town, South Africa, 25-28 May 2004. This venue will provide an excellent opportunity to bring together regional scientists in southern Africa and statistical climatologists from other parts of the world and to improve the reporting of climate change indices from southern Africa.

The ET/CCDMI will maintain an active overview of climate monitoring activities, and of climate change detection research. For more information on climate monitoring, please see the article in this issue of the *WMO Bulletin* "the Earth's climate in historical perspective: a climate of continuing change". The ET/CCDMI intends to actively participate in the US NOAA/DOE "Ad Hoc Detection Group", the newly endorsed CLIVAR Climate of the 20th century project (Folland *et al.*, 2002), and liaison with the Working Group on Climate Modelling (WGCM). The team will continue to evaluate and promote the use of indices for climate change detection and is planning to provide input to the IPCC Fourth Assessment Report. It also plans to participate in the development of a joint Global Climate Observing System (GCOS) and ET/CCDMI branded Website that updates indices of climate change and variability in near real time.

The ET/CCDMI would welcome information from other teams, panels and working groups concerned with the improvement and extension back in time of global historical datasets and on the developments in areas related to the work of the ET. Topics of particular interest include data archaeology, use of proxy data, and the homogeneous extension of such datasets into the future, sometimes using new (e.g. satellite) technology. The team is also interested to hear from scientists and organizations interested in regional climate change workshops.

Finally, there are many aspects of the ET/CCDMI's work that are relevant to applications and policy. Contributions from the climate change detection community will be extremely important to the IPCC Fourth Assessment Report, and the policy synthesis that derives from that assessment will be hugely influential in setting government climate policy throughout the world. These contributions are broadly influential across a broad spectrum of the science, including monitoring climate change, impacts and adaptation research, the validation of climate models, the detection of anthropogenic change across a broad spectrum of climate indicators and regions, and the projection of future change.

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